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RESEARCH DEPARTMENT

A BAND V SIGNAL-FREQUENCY UNIT FOR A V.H.F./U.H.F. FIELD-STRENGTH RECORDING RECEIVER

Report No. G-056/3

(1962/8)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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March 1962

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A BAND V SIGNAL-FREQUENCY UNIT FOR A V.H.F./U.H.F. FIELD-STRENGTH RECORDING RECEIVER

SUMMARY

The report describes a signal-frequency unit, for use in Band V (610-960 Mc/s), which forms part of a v.h.f./u.h.f. field-strength recording receiver. Details are given of the mechanical and electrical design of the unit and some problems which arose in its development are discussed. The unit includes two coupled coaxial line resonators for signal-frequency tuning and a crystal-controlled local oscillator, the frequency multiplier of which uses only conventional valves rather than special u.h.f. valve types. Results of performance tests are given which show that the unit meets the requirements of the specification for the complete receiver.

1. INTRODUCTION

A receiver for recording field-strength in the frequency bands allocated for television broadcasting in the United Kingdom, namely Band III (174-216 Mc/s), Band IV (470-585 Mc/s), and Band V (610-960 Mc/s) has been described in an earlier report.[1] This receiver, which is of the superheterodyne type, consists of three interchangeable signal-frequency (s.f.) units and a main unit containing the intermediate-frequency (i.f.) amplifier, detector and post-detector circuits. When that report was issued the Band V signal-frequency unit was still being developed and so it was not possible to include a full description of it. Development has now been completed and this report describes the Band V s.f. unit and so may be considered as an addendum to the earlier report. A method of increasing the sensitivity of the receiver by means of a correlation detector has been discussed in a second report.[2]

2. SPECIFICATION

The special purpose for which this receiver was designed and the specification evolved to make it suitable for this task were stated and discussed in the first report.[1] The specification is repeated in Section 2.1 below.

2.1. Specification for a V.H.F./U.H.F. Field-Strength Recording Receiver

"The receiver must be able to record the field strength of special transmissions on any frequency in the ranges 174-216 Mc/s and 470-960 Mc/s. These transmissions will be square-wave modulated to a depth of 100% at 1000 c/s ± 1 c/s and the carrier frequency controlled to within 0·01% of the nominal frequency. Continuous tuning is not necessary and the signal-frequency circuits of the receiver may be fixed before installation.

"For normal operation, the output of the receiver shall be proportional to the logarithm of the input signal, but facilities shall be provided for a linear relationship if required. The recording error, referred to the input, shall be less than ± 1 dB during a period of up to one month after inspection and calibration, provided that the supply voltage remains within the range 190–250 V r.m.s. The useful gain shall be limited only by fluctuation noise and the noise factor be as low as is reasonably possible, with a maximum of 15 dB. Provision shall also be made for recording the field strength of unmodulated transmissions."

2.2. Specification for the Band V Signal-Frequency Unit

Since the Band V s.f. unit is an integral part of the receiver its general form and certain detailed requirements were already determined. For example, it was necessary that it should be interchangeable with the other two s.f. units and suitable for use with the existing main unit for which an i.f. of 10·7 Mc/s had been chosen. The following specification for the Band V unit was derived from these requirements and the specification for the whole receiver.

(i) The unit shall be suitable for use with an aerial and feeder system providing a nominal source impedance of 71 ohms.
(ii) The i.f. circuit must be suitable for direct connexion to the standard main unit.
(iii) When used with the standard main unit, having an i.f. noise factor of 3·2 dB, the over-all noise factor shall be less than 15 dB.
(iv) The local oscillator shall be maintained within ± 100 kc/s of the nominal frequency. This requires a stability of better than 0·01% at the highest frequency.
(v) The rejection of the image-frequency shall be not worse than that provided by the Band IV unit, that is not worse than 20 dB.
(vi) The long-term gain stability of the Band V unit must be such that, when it is used with the standard main unit, the over-all stability of the receiver complies with the specification.

3. DESCRIPTION OF THE BAND V SIGNAL-FREQUENCY UNIT

3.1. General

A photograph of the unit is shown in Fig. 1. Fig. 2 gives the circuit diagram.

The basic design of the Band V unit is similar to that of the Band IV unit. A diode frequency changer is preceded by a coaxial line resonator signal-frequency tuner without a signal-frequency amplifier. The local oscillator consists of a crystal-controlled oscillator followed by several stages of frequency multiplication, the final tuned circuit of which is also a coaxial line resonator. However, the higher frequency and greater frequency range of Band V required considerable development, particularly in ensuring adequate image-frequency rejection and local oscillator power.

The final design of the unit shows two major differences from that of the Band IV unit.

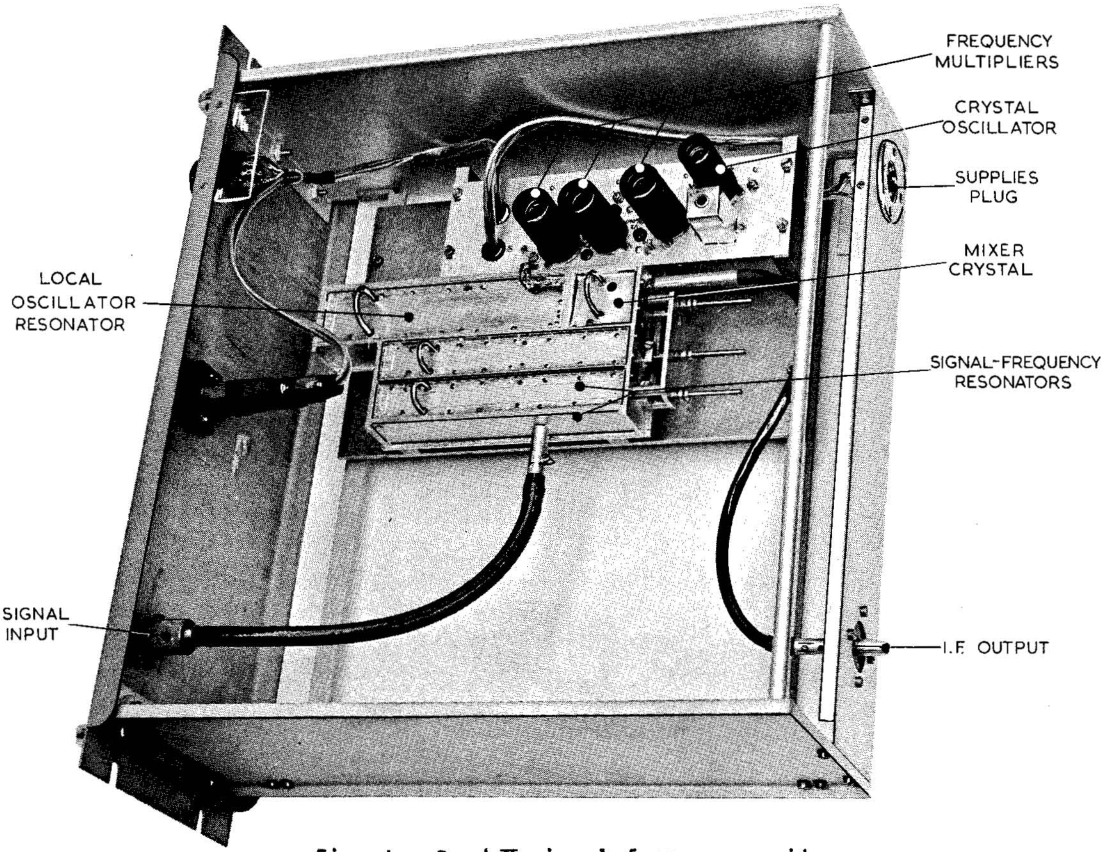


Fig. I - Band V signal-frequency unit

(i) Signal-frequency tuning is provided by a coupled pair of coaxial line resonators whereas the Band IV unit has only a single signal-frequency resonator.

(ii) An extra stage has been provided in the local-oscillator frequency-multiplier chain.

The main chassis is of strip and plate construction and has a 19 in × 7 in (48 cm × 18 cm) front panel for rack mounting like the units for Bands III and IV. The r.f. input socket and metering jack are on the front panel while the i.f. output and power input sockets are at the rear.

There are two main sub-units, the tuning sub-unit and the local-oscillator sub-unit. These are mounted together on a 3/16 in (0·48 cm) thick duralumin plate which is itself fixed to the main chassis strips by shock-absorbing mountings.

3.2. Tuning Sub-Unit

3.2.1. Resonator Construction

The tuning sub-unit consists of three coaxial line resonators and a compartment for the mixer crystal and its i.f. circuit. Two identical resonators of 1 in × 1 in (2·54 cm × 2·54 cm) cross-section form the signal-frequency tuned circuit while the third, of 1½ in × 1 in (3·81 cm × 2·54 cm) cross-section, is the local oscilator resonator. The main structure of this sub-unit is fabricated in

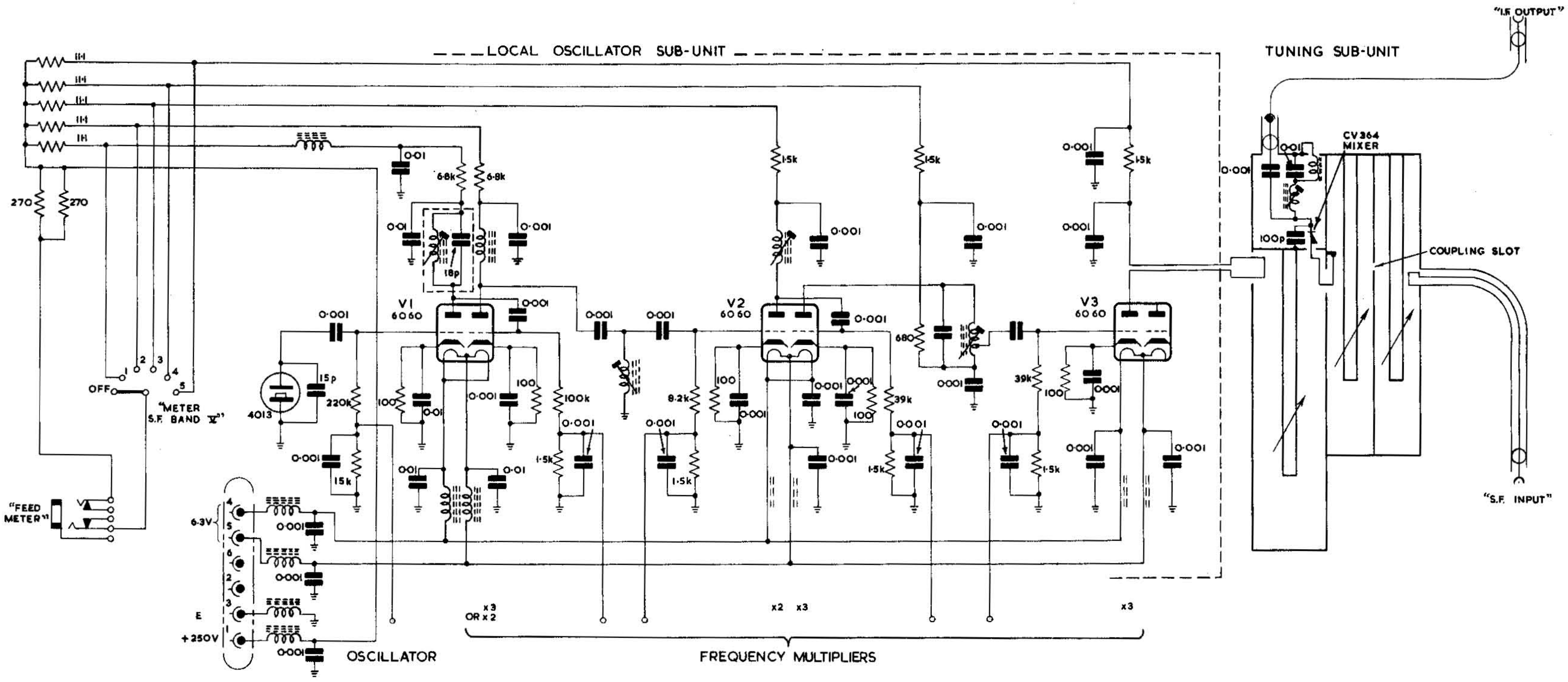


Fig. 2 - Circuit diagram of Band V unit

brass sheet which is then silver-plated to a minimum thickness of 0·0005 in (0·013 mm) to ensure high conductivity. Milled slots in the base plate are used to position the vertical walls and ensure adequate dimensional accuracy, while removable lids with spring contacts allow ready access to components inside the cavity.

Compared with the tube construction employed for the Band IV unit, the present construction is simpler (bearing in mind that three tubes would be needed) especially when inter-cavity coupling arrangements are considered.

3.2.2. Tuning

The system for tuning the three resonators is the same as that used in the Band IV unit, which has proved very satisfactory. Each resonator is a coaxial quarter-wave line short-circuited at one end and open-circuited at the other. The inner conductor consists of a tube which telescopes inside a larger diameter fixed tube. Adjustment is made by means of a rod of "Nilo 36" low-thermal-expansion alloy running inside the tubes and pinned to the smaller tube at the open-circuited end of the line. After adjustment, the rod is clamped to the cavity wall at the short-circuited end, thus ensuring stability of the inner conductor length. The tubes are of silver-plated brass and the contact between them is a ring of silver wire located in a groove at the end of the fixed tube. For ease of tuning the rod passes, with a friction grip, through a threaded bush; it may thus be pushed or pulled directly to give a coarse adjustment, or rotated by a knob so that the thread operates in a fixed plate to give fine adjustment.

3.2.3. Coupling Circuits

The coupling to the first signal-frequency cavity is by a small adjustable loop connected to the receiver input socket by a flexible coaxial cable. The two signal-frequency cavities are loosely coupled by a slot in the wall between them. This acts as a common inductance in the outer conductor of the two resonators. The signal is finally coupled to the mixer diode by a loop which passes through the opposite wall of the second cavity into the oscillator cavity, where it makes contact with one terminal of the diode. By this means, oscillator power is also coupled to the mixer. The mixer is loaded by an i.f. circuit in a separate compartment at the rear of the oscillator cavity. The diode holder incorporates a plate and sheets of mica which form a capacitance to the rear wall of the oscillator cavity, thereby completing the r.f. circuit.

The coupling loops into and out of the signal cavities, as well as the coupling slot between them, are placed at some distance from the short-circuited end of the lines, rather than at the point of short-circuit. This enables the circuits to be tuned over the whole band with a minimum of coupling adjustments and to have an absolute-frequency bandwidth which is nearly constant. (See Appendix, Section 8.1).

The tuning condition recommended is one close to the "transitionally coupled" condition for which the r.f. response has the flattest maximum. However, as shown in the Appendix, Section 8.2, the match at the r.f. input can be perfect for this condition only if the cavities have an infinite (unloaded) Q-factor, i.e. if they are completely loss-free. The receiver is therefore aligned for a good response shape when fed from a source impedance equal to the nominal input impedance (71 ohms).

The input v.s.w.r. is then checked and, if poorer than 0·67, slight readjustment of the input coupling loop and the first cavity tuning is made to improve the match. The disturbance to the response curve is slight and is in the direction of an "under-coupled" response, i.e. one with a single maximum not quite as flat as for transitional coupling. Since the r.f. response shape will be affected by changes in the loading of the first cavity, it is recommended that the aerial v.s.w.r. as seen by the receiver should be not lower than 0·75.

During development there was some difficulty in designing a fixed mixer coupling loop which gave satisfactory loading of the signal cavity as well as adequate oscillator coupling over the whole band, but a design that appeared to achieve this was finally evolved. Subsequently some difficulty arose in a fairly narrow range of frequencies around 775 Mc/s, apparently due to insufficient loading of the signal cavity. It was found that the difficulty could be overcome by adding, for operation in this frequency range, a small capacitance to earth at the point of connexion to the mixer diode. This suggests that some resonance effect in the loop is coming into play, but the matter has not been investigated further.

3.3. Local-Oscillator Sub-Unit

3.3.1. Construction

The local-oscillator sub-unit employs a small flat chassis bolted to two duralumin blocks attached to the main base plate. The output is coupled into the oscillator cavity of the tuning sub-unit by a wire loop which projects into the cavity resonator through a small hole. Adjustment of the coupling is achieved by movement of the local oscillator sub-unit, the fixing holes being slotted to allow for this. By varying the penetration of the loop into the resonator in this way, the optimum mixer crystal current may be obtained.

3.3.2. Type of Oscillator and Choice of Multiplication Factor

The local oscillator consists of a crystal-controlled oscillator followed by four stages of frequency multiplication. The local-oscillator resonator forms the anode tuned circuit of the final multiplier. With the type of circuit employed the maximum frequency for which crystals were readily obtainable was 20 Mc/s and so an over-all multiplication factor of 54 was chosen for the higher local-oscillator frequencies. However, at the lowest local-oscillator frequencies an over-all multiplication by 54 requires a crystal-oscillator frequency of about 11 Mc/s. Signals at frequencies separated by this frequency might be generated in the multiplier chain and produce spurious signals in the i.f. amplifier close to 10·7 Mc/s with sufficient power to affect the receiver performance. For this reason an over-all multiplication by 36 was chosen for local-oscillator frequencies less than 675 Mc/s.

3.3.3. Multiplication Scheme and Valve Type

The Band IV multiplier used two double triodes type 12AT7, the crystal oscillator being followed by three stages multiplying by factors of 4,3 and 3. With the larger over-all multiplication factor, 54, required for the higher-frequency portion of Band V, and the known difficulty of obtaining sufficient grid drive for the final multiplier when using large factors in the earlier stages, it was found necessary to use four multiplier stages. The highest multiplication factor in any one stage could then be limited to 3.

Three double triode valves type 6060 (a special quality version of type 12AT7) are used. V1 is used for the crystal oscillator and first multiplier circuits, V2 for the second and third multipliers and a half of V3 for the fourth multiplier stage. The multiplication scheme is given in Table 1.

TABLE 1

Stage	Local Oscillator Frequency less than 675 Mc/s		Local Oscillator Frequency greater than 675 Mc/s	
	Stage multiplication factor	Output frequency of stage	Stage multiplication factor	Output frequency of stage
Crystal oscillator	1	f_c	1	f_c
First multiplier	2	$2f_c$	3	$3f_c$
Second multiplier	2	$4f_c$	2	$6f_c$
Third multiplier	3	$12f_c$	3	$18f_c$
Fourth multiplier	3	$36f_c$	3	$54f_c$

3.3.4. Circuit Design

The quartz crystal is a BT-cut plate in an evacuated glass envelope with a B7G type base. The total frequency tolerance is 0·01% of the nominal frequency. The crystal is connected as the grid element of a tuned-anode-tuned-grid oscillator.

The multipliers are class-C amplifiers with single-tuned anode circuits to select the required harmonic of the grid circuit frequency. The anode tuned-circuit of the final multiplier is the local-oscillator coaxial line resonator; the other circuits consist of coils tuned entirely by stray circuit capacitances. The range of inductance values required for tuning over the complete frequency range is obtained in the anode circuit of the crystal oscillator and of the first and second multipliers by using iron-dust cores at the lower frequencies and copper cores at the higher frequencies

The design of the third and fourth multiplier stages is discussed separately below.

The grid current of each triode may be measured by external meters connected to test points on the upper side of the chassis plate. Facilities for monitoring anode currents are provided by a selector switch and a meter jack on the front panel.

Decoupling of the heater leads of V2 and V3 is provided by ceramic condensers and by ferrite beads threaded over the supply wires. Wire-wound chokes are used for the heater supply of V1.

3.3.5. Design of the Third and Final Multiplier Stages

The crystal oscillator and the first two multipliers follow the design of the Band IV unit fairly closely, but the design of the third and fourth multipliers necessitated considerable development. It is convenient to discuss these two stages together.

The final local-oscillator frequency required lies in the band 589–971 Mc/s, where special u.h.f. valve types are normally used. Nevertheless a more conventional valve such as the type 6060 (12AT7) is useful as an oscillator at frequencies up to about 500 Mc/s. This suggested that it could function satisfactorily as a multiplier for input frequencies up to at least 300 Mc/s. The advantages of the use of a conventional valve rather than a special u.h.f. type are as follows:

(a) They are readily available, inexpensive and possess good reliability.
(b) Being constructed on a normal pin-type base they allow a more compact and convenient mechanical layout than, for instance, disc-seal valves.
(c) The number of valve types used in the receiver need not be increased.

Again, for reasons of compactness and ease of construction, a lumped tuned circuit, rather than a line resonator, was used at the grid of the final multiplier valve. This means, in practice, an upper frequency limit of about 300 Mc/s for this circuit; a multiplication factor of 3 is therefore required for the final stage and the grid circuit must be tunable from 200–325 Mc/s to cover Band V. It was found that the same coil could be used over the complete frequency range in both the third and fourth multiplier stages, using copper or iron-dust cores for adjustment, provided that, in the case of the final stage, different tapping points are used in different parts of the frequency range, and suitable changes are made to the grid coupling capacitor. Also, one part of the range requires the addition of a capacitor in parallel with the coil. Several changes are thus required in this scheme, but it was preferred to an earlier design in which, although there were fewer combinations over the band, the coil had to be changed.

One of the difficulties met was that, at certain frequencies, the provision of a reasonable drive voltage at the final multiplier grid did not always ensure adequate third harmonic output. This is believed to be due to resonance effects associated with the grid-anode capacity giving rise to a low impedance across the output at the third harmonic frequency; since the grid-to-earth impedance would form part of this low impedance network, changes in the grid circuit arrangement could affect the output considerably. The circuit adjustments described above enabled this difficulty to be overcome.

4. RESULTS OF PERFORMANCE TESTS

The Band V s.f. unit has been found to operate satisfactorily at all frequencies within the specified range including the maximum frequency of 960 Mc/s. Results of performance tests at three representative frequencies are given below.

4.1. Selectivity

The frequency responses of the s.f. circuit of the Band V unit are shown in Fig. 3. Over a frequency range of ± 200 kc/s about the nominal frequency, which corresponds to the 400 kc/s pass-band of the main unit, the responses are within 0·2 dB of the value at band centre.

Table 2 gives the type and amplitude of spurious responses which occur when using the Band V unit. They show the relative amplitude of a signal at the spurious frequency which causes an error of 1 dB in the indicated amplitude of a fixed reference signal in the pass-band. These tests were made with the receiver operating on c.w. at a fixed gain. The open-circuit voltage of the reference signal applied to the input of the Band V unit was 10 μV. No i.f. attenuators were inserted.

TABLE 2

f_o = signal frequency
f_b = final local-oscillator frequency
f_c = crystal frequency
f_i = intermediate frequency
n = overall local-oscillator multiplication factor

Type of Response	Input voltage at spurious frequency relative to a 10 μV reference signal at f_o for 1 dB error, dB		
	f_o = 659·75 Mc/s $f_b > f_o$ $n = 36$	f_o = 774·0 Mc/s $f_b < f_o$ $n = 54$	f_o = 870·65 Mc/s $f_b < f_o$ $n = 54$
$f_b + f_i$ (image)	43	–	–
$f_b - f_i$ (image)	–	49	38
$(n - 1) f_c - f_i$	> 78	> 90	> 84
$(n - 1) f_c + f_i$	48	> 90	83
$(n + 1) f_c - f_i$	> 79	62	54
$(n + 1) f_c + f_i$	> 79	76	78
f_i (i.f. breakthrough)	71	62	> 90
Other responses	> 60	> 60	> 60

4.2. Sensitivity and Input Impedance

Table 3 shows the measured values of noise factor, conversion loss and input v.s.w.r. at the three test frequencies. The i.f. noise factor was 3.2 dB.

The earlier report[1] on the whole receiver includes typical calibration curves obtained for various conditions of operation. Such curves are largely determined by the characteristics of the main unit, except at low values of input signal where the noise factor has an important influence. The calibration curves for a receiver consisting of the Band V unit and the main unit are very similar to those obtained when the Band IV unit is in use. Curves for the latter case, when the

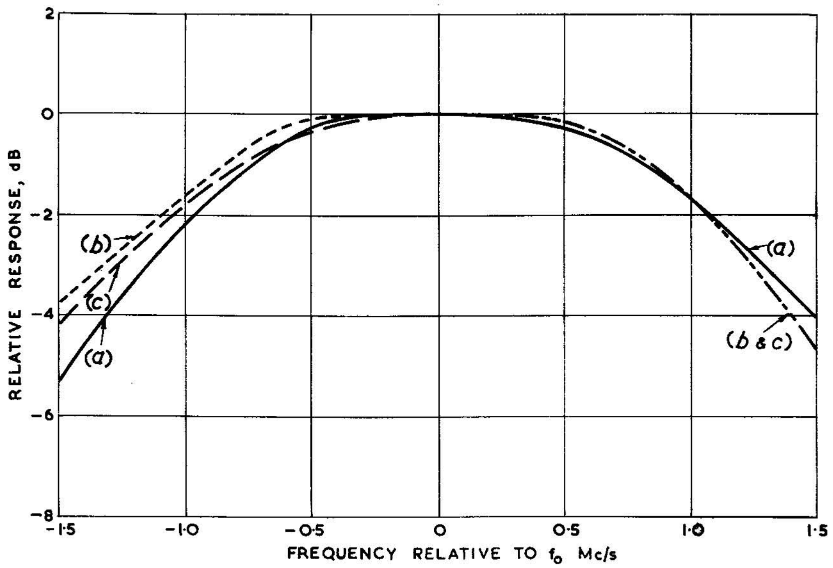


Fig. 3 - Frequency response of Band V unit

(a) f_0 = 659·75 Mc/s
(b) f_0 = 774·0 Mc/s
(c) f_0 = 874·65 Mc/s

special test transmissions described in the specification are being received, have been given in another report[2] which discusses the improvement in sensitivity which may be expected to be obtained by the use of increased a.f. gain and a correlation detector working at 1 kc/s.

TABLE 3

Test	Measured Value		
	f_0 = 659·75 Mc/s	f_0 = 774·0 Mc/s	f_0 = 870·65 Mc/s
Noise factor, dB	10·9	12·2	11·6
s.f. unit loss, dB	8·8	7·2	7·0
Input v.s.w.r.	0·72	0·68	0·78

4.3. Local-Oscillator Radiation

Local-oscillator radiation has been measured in terms of the open-circuit voltage available at the aerial input socket and was found to be 1 mV. This test was carried out with the receiver tuned to receive a signal at 774 Mc/s with the local oscillator working at a frequency of 763·3 Mc/s.

4.4. Stability

A Band V unit was tested in an oven over the temperature range 20°C to 50°C. The overall change of gain of the receiver, including the main unit which was operated at room temperature, was not more than ± 0·3 dB. The time required, after switching on, before the receiver had reached its final calibration, was approximately 5 minutes.

5. CONCLUSIONS

The results of tests show that the performance of the Band V s.f. unit meets the requirements derived from the specification of the whole v.h.f./u.h.f. field-strength recording receiver. In particular the noise factor of less than 13 dB is satisfactory.

The unit is, in effect, a further development of the design of the Band IV unit and could, if necessary, be modified easily to operate in Band IV.

The adoption of a two-resonator signal-frequency tuning system has provided a very useful improvement in the image-frequency rejection performance as compared with that of the Band IV unit. The success in extending the range of the frequency multiplier sub-unit to cover Band V without resorting to the use of special u.h.f. valves is very satisfactory from an operational point of view.

6. ACKNOWLEDGEMENT

Mr. G.F. Newell was responsible for the design of the prototype coaxial line resonators, which employed a rectangular rather than circular cross-section and incorporated a pair of signal-frequency resonators coupled to give nearly constant bandwidth at all frequencies in Band V.

7. REFERENCES

1. "A V.H.F./U.H.F. Field-Strength Recording Receiver", B.B.C. Research Department Report No. G-056, Serial No. 1955/13, April 1955.

2. "A Correlation Detector: Its Application to a V.H.F./U.H.F. Field-Strength Recording Receiver", B.B.C. Research Department Report No. G-056/2, Serial No. 1957/20, September 1957.

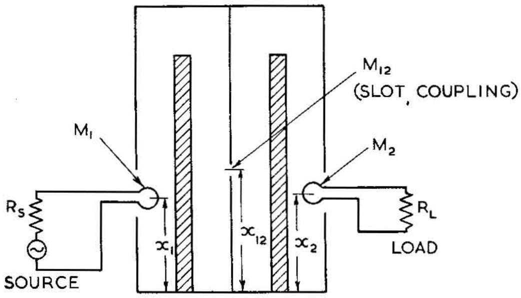
3. Staff of the Radio Research Laboratory, Harvard University, "Very High-Frequency Techniques", Vol.II, p.772, First Edition, New York and London: McGraw-Hill Book Company, Inc., 1947.

8. APPENDIX

8.1. Optimum Positions for the Coupling Elements in a Pair of Coaxial-Line Resonators

The arrangement considered is that used for the Band V signal-frequency tuner described in Section 3 and shown diagrammatically in Fig. 4. It is assumed that the impedances of the source and load are purely resistive and independent of the tuned frequency, f_0, of the resonators. It is also assumed that the losses of the resonators are negligible. It may be shown that this arrangement is equivalent to the circuit of Fig. 5, the components of which are found by evaluating the equivalent elements of Fig. 4 at the short-circuited ends of the coaxial lines.

Fig. 4 - Diagrammatic representation of signal-frequency cavities

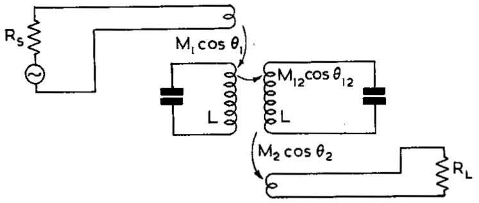


Neglecting disturbances of the field in the resonators due to the coupling elements and line imperfections, the current in the line follows a cosine law. Therefore a mutual inductance M placed at a distance x from the short-circuited end of a resonator is represented in Fig. 5 by a value $M \cos \theta$ where

$$\theta = \frac{2\pi f_0 x}{v}$$

and v is the velocity of propagation in the line.

Fig. 5 - Equivalent circuit of signal-frequency cavities



In the tuner it was desirable that, for any chosen value of f_0,

(a) the shape of the response curve should be close to that of a transitionally-coupled (maximally-flat) pair of circuits,

and

(b) the bandwidth, B, at the half-power points of the response curve should be substantially constant.

If possible, these requirements should be achieved without making any mechanical adjustment to the coupling elements when f_0 was changed.

It is shown in Section 8.2 that, when the losses of the tuned circuits are negligible, the optimum power match is obtained when the damping from the source and load gives the two circuits the same magnification factor, Q, and we shall for convenience consider this case only. The coupling coefficient between the two circuits, referring to Fig. 5, is

$$k = \frac{M_{12} \cos \theta_{12}}{L}$$

and, if

$$kQ = 1 \tag{1}$$

the response if maximally flat and has a half-power bandwidth of

$$B = \sqrt{2}\frac{f_o}{Q} \, . \tag{2}$$

To satisfy the conditions (a) and (b) above, the bandwidth and response shape are only independent of f_o if

$$Q \propto f_o \tag{3}$$

and

$$k \propto 1/f_o \, . \tag{4}$$

The inductance L in Fig. 5 can be shown[3] to have a reactance

$$2\pi f_o L = \frac{\pi}{4} Z_o \tag{5}$$

where Z_o is the characteristic impedance of the line.

The magnification factor of this circuit is

$$Q = \frac{2\pi f_o L}{R} = \frac{\pi Z_o}{4R} \tag{6}$$

where R is the effective series resistance coupled into either circuit from the source or load. Since the circuits have the same values of Q and Z_o, they have the same values of L and R. R can be shown to be

$$\begin{aligned} R &= (2\pi f_o M_1 \cos \theta_1)^2 / R_s \\ &= (2\pi f_o M_2 \cos \theta_2)^2 / R_L \end{aligned}$$

and if, as is convenient, $x_1 = x_2 = x$ in Fig. 4, then

$$\theta_1 = \theta_2 = \theta = \alpha f_o$$

where

$$\alpha = \frac{2\pi x}{v}$$

and so, from equation (6),

$$Q \propto \frac{1}{f_o^2 \cos^2 \alpha f_o} \, . \tag{7}$$

From Fig. 5 and equation (5)

$$k = \frac{M_{12} \cos \theta_{12}}{L} = \frac{8 f_o M_{12} \cos \theta_{12}}{Z_o} .$$

Therefore

$$k \propto f_o \cos \alpha_{12} f_o \qquad (8)$$

where

$$\alpha_{12} = \frac{2\pi x_{12}}{v} .$$

From (7) and (8) we have

$$kQ \propto \frac{f_o \cos \alpha_{12} f_o}{\{f_o \cos \alpha f_o\}^2} \qquad (9)$$

and from (2) and (7)

$$B \propto f_o^3 \cos^2 \alpha f_o . \qquad (10)$$

Equation (10) is strictly true only if the transitionally-coupled condition is maintained.

Although kQ and B are not independent of frequency as desired, the variation may be reduced by operating in the region where the rate of change with respect to f_o is zero. Assuming that, by this means, the variation of kQ can be kept small, equation (10) may be used to find the condition for zero rate of change of bandwidth. By differentiating (10) with respect to f_o the required condition is found to be

$$\theta = \alpha f_o = 57^\circ. \qquad (11)$$

Then, assuming that the constancy of expression (10) is fulfilled, equation (9) may be written

$$kQ \propto f_o^2 \cos \alpha_{12} f_o \qquad (9a)$$

and the condition for zero rate of change of kQ with f_o is

$$\theta_{12} = \alpha_{12} f_o = 62^\circ . \qquad (12)$$

If, therefore, x and x_{12} are so chosen that α and α_{12} fulfill equations (11) and (12) when f_o is equal to the mean frequency of Band V, a near-optimum performance will be obtained. The bandwidth, B, at the extreme frequencies of Band V is reduced by only 30% of its value at the mean frequency and kQ lies between the values 1 and 0·935 over the whole band. These results may be compared with the situation when the coupling elements are placed as near as practicable to the short-circuited end, when there would be an increase of bandwidth by a factor of more than three and a reduction of kQ from 1 to 0·64 when f_o is changed from the lowest to the highest frequency of Band V.

The value of x used in the Band V tuner is that given by the above analysis but the value of x_{12} is rather less than the optimum. The effect is to allow a slight increase in bandwidth at the higher frequencies, and to require the ratio of external damping to the small internal circuit loss to vary less over the frequency range than in the theoretically optimum design.

8.2. Effect on Impedance Matching of the Frequency Response Characteristic of a Pair of Coupled Circuits

For a discussion of the response characteristic we consider the simplified representation of the receiver input circuit given in Fig. 6. This shows a pair of coupled circuits in which resistive components due to both circuit losses and external connexions are represented by conductances across the tuned circuit. The damping of the first circuit has been represented by two components, namely G_s arising from the aerial circuit, and G_d which represents loss in the tuned circuit itself. The terminal pair AA' therefore represents, in an idealized form, the input connexion to the receiver. In the second circuit, all losses (including the effect of the load) are represented by a conductance G_2. If we take $G_1 = G_s + G_d$, the input and output voltages, $\boldsymbol{V}_1$ and $\boldsymbol{V}_2$, may be expressed as follows in terms of the input current I.

$$\boldsymbol{V}_1 = \frac{I}{G_1} \cdot \frac{1 + jx}{(1 + jx)\ (1 + jqx) + n^2}$$

$$\boldsymbol{V}_2 = \frac{I}{G_1} \cdot \frac{-j n\sqrt{p/q}}{(1 + jx)\ (1 + jqx) + n^2} \cdot$$

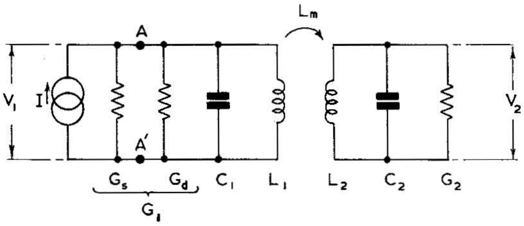


Fig. 6 - Representation of coupled circuits, including losses

It is assumed that the combinations C_1, L_1 and C_2, L_2 are both tuned to the frequency $\omega_0/2\pi$ and that $L_m^2 < < L_1 L_2$. The other symbols have the following significance:

$$k = L_m/\sqrt{L_1 L_2}$$

$$n = k\sqrt{Q_1 Q_2} \text{ where } Q_1 = \frac{\omega_0 C_1}{G_1} \text{ and } Q_2 = \frac{\omega_0 C_2}{G_2}$$

$$p = L_1/L_2 = C_1/C_2$$

$$q = Q_1/Q_2$$

$$x = 2Q_2 \cdot \frac{d\omega}{\omega_0}$$, where $\omega_0 + d\omega$ is the angular frequency with

$$d\omega << \omega_0 .$$

At the mid-band frequency ω_0, $x = 0$ and we have

$$\boldsymbol{V}_1 = \frac{I}{G_1(1 + n^2)} \cdot$$